S p e c i f i c a t i o n

Be It Known That We, **VLAD OCHER** a citizen of the United States of America, resident of the County of San Diego, State of California, **FRANK J. POLESE**, a citizen of the United States of America, resident of the County of San Diego, State of California and **JACK A. RUBIN**, a citizen of the United States of America, resident of the County of San Diego, State of California have invented a new and useful

HOMOGENEOUS SHAPED CHARGE LINER AND FABRICATION METHOD

of which the following is a specification:

Field of the Invention

This invention relates to explosive shaped charges and more particularly forming shaped charge metal liners used, for example, in oil well perforating.

Background of the Invention

It is well known to use shaped charges for the purpose of creating perforations in well bores to extract a marketable flow of oil, gas or other material from a given well, as disclosed in Reese et al., U.S. Patent Application Publication No. US 2002,0007754 and Jacoby et al., U.S. Patent No. 6,349,649 incorporated herein by this reference. In general, a metal liner is formed into a shape which, during an explosion, guides and focuses explosive gasses to form a high velocity jet which perforates the oil-producing strata. Liner shapes are selected according to the strata being perforated and can be conical, bi-conical, hemispherical, tulip or trumpet shaped, among others.

Liners can be made from solid metal such as the deep-drawn liners disclosed in Jacoby *supra*. Solid metal liners generally suffer from the disadvantage of allowing a "slug" or "carrot" to form. Carrots are sections of the shaped charge liner that form into solid bodies after detonation and do not become part of the shaped charge jet but rather can interfere with it and/or later become lodged in the perforation created by the jet. To diminish "carrots", porous metal liners have been formed by compressing powdered

metal into the desired liner shape. As disclosed in Pratt et al., U.S. Patent No. 6,354,219, liners have been formed by mixtures of two or more different powdered metals along with potentially binder and lubricant materials. Typically, one of the metals is a higher density metal and the other metal acts as a binder or forms a matrix to bind together particles of the heavier metal. The use of powdered metals allows for inexpensively forming the liners into the many different liner shapes. Many metals and alloys have been used for the heavy metal including tungsten, hafnium, depleted uranium, bismuth, molybdenum and various alloys thereof among others, while metals used as the binding metal include copper, lead, zinc, tin, cadmium and various alloys thereof among others.

However, due to the differences in the specific gravities and melting points of the two powdered metals, and the lack of mutual solubility of metals such as copper and tungsten, for example, it is difficult to form composites of those two metals that exhibit a reliable degree of homogeneity using conventional techniques of compression or compression and sintering.

It is also known that to maximize penetration depth for the perforation, it is preferable to form a coherent jet generally consisting of a continuous stream of small particles traveling at as high a velocity possible without encountering the degrading effects of surpassing sound speed for the given liner material. It has been found that a more

homogeneous distribution of higher density particles within the liner material will enhance the coherence of the jet.

One solution has been proposed by Brooks et al., U.S. Patent No. 6,296,044 and generally involves mixing particles of two different melting point metals and an organic binder together into a homogeneous feedstock for injection molding. Alternately, the lower melting temperature metal of the two metals can act as the binder. In general, the disadvantages of this method are that it requires extended debinding time leading to low productivity rates, and suffers from generating compact preforms having a high percentage of cracking.

The instant invention results from an attempt to devise a simpler and more practical process to manufacture shaped charge liners using powdered metallurgy techniques but which also results in improved homogeneity.

Summary of the Invention

The principal and secondary objects of this invention are to provide a practical and simple process to precisely form shaped charge liners combining high density metal particles with lower density binding or agglutinating metals in a homogeneous structure.

These and other objects are achieved by pre-agglomerating particles of a high specific gravity metal with an agglutinating, different density metal to form a free-flowing powder of pre-agglomerated particles which are

then press-molded or tap-molded to form near net-shape liner preforms. The preforms are then partially sintered and then hot-coined or forged to form the final shape liner.

Pre-agglomeration can occur in several ways. In a first embodiment, particles of different density metals are pre-bonded together by an adhesive in a way which allows the bond between the two metals to be breakable during the press-molding step. In another embodiment, free-flowing powder is selected of pre-clustered nodules of the two metals, where each nodule comprises a grouping of subnodules wherein each subnodule includes a core made of the denser metal surrounded by a blanket of smaller particles of the agglutinating metal bonded by coreduced metal oxides. In another embodiment, free-flowing powder is selected of pre-clustered nodules of the two metals, where each nodule comprises a grouping of subnodules wherein each subnodule includes at least one particle of each of the different density metals. The nodules are breakably agglutinated by coreduced metal oxides. Within each subnodule, the particles are paired by surface diffusion occurring during the fabrication process.

Brief Description of the Drawing

Figure 1 is a block diagram illustration of the manufacturing process according to the invention.

Figure 2 is a diagrammatical illustration of a pre-agglomerated metal powder.

Figure 3 is a diagrammatical illustration of an alternate pre-agglomerated metal powder.

Figure 4 is a diagrammatical illustration of an alternate pre-agglomerated metal powder.

Description of the Preferred Embodiment of the Invention

Referring now to the drawing, as shown in Figure 3, there is shown a simplified process of the invention where a volume of free-flowing sinterable powder made of pre-agglomerated particles of at least two metals is selected **1** and then press-molded **2** into a compact preform **3** having the desired net shape of the shaped charge liner for use in oil well perforation. The pressing is done under a pressure of a range of approximately 1350 to 3400 atmospheres (20,000 to 50,000 lbs/in^2).

Alternately, the free-flowing powder can be suspended in a volatile carrier such as an organic binder such as wax, polyester resin, polyethylene or polypropylene to form a feedstock for an injection molding step. Free-flowing powder refers those powders so having a flowability defined by the Metal Powder Industry Federation (MPIF).

The preform **3** is then partially sintered **4** at ambient pressure and at a temperature just above the melting point

of the metal having a lower melting point to form a partially sintered body **5**. If the lower melting point metal is copper, then that temperature will range between 1090°C and 1230°C.

The partially sintered body is strong enough to withstand the rigors of further individual automated manipulation and processing. Partial sintering also prevents unwanted overflow of the melted lower temperature metal to the surface of the body. The melted metal is partially constrained by adjacent unmelted particles.

The partially sintered body is then maintained at a temperature of between 200°C and 800°C and then hot-coined or forged **6** in a hydraulic press under a pressure within a range of approximately 1350 to 6800 atmospheres (20,000 to 100,000 lbs/in^2) to form the final shape liner **7**. The coining or forging step allows for the inexpensive automated creation of liners within acceptable tolerance without significant additional machining. However, the liner may be machined **8** if necessary to further desired tolerances. Final machining can also include various other finalization steps such as annealing, grinding, lapping, stripping, cleaning or other known processing.

In general, the term "coining" means pressing an existing body or plug so as to reshape it without removing a large portion of material. The term "forging" in this specification generally means coining while the material has been heated.

Now will be described the preferred free-flowing powder for use in the above described process. The preferred powder is made of clusters of agglomerated particles of at least two metals having different densities and melting points. A first type of particle is made of a metal or alloy having a melting point of less than 1500°C such as copper and alloys thereof. A second type of particle is made from a metal or alloy having a melting point of more than 1500°C and a density of at least 10 g/cm^3. Tungsten and molybdenum are preferred choices that can be used singly or together. These metals exhibit a higher density than those of the first type, and a higher melting point. They also have lesser coefficients of thermal expansion.

By adjusting the weight ratio of the first type to the second type of metals within a range of between approximately 5 and 30 percent, one can create a sintered liner of adequate strength, homogeneity and desired density.

Various different types of clusters of pre-agglomerated may be used to form the preferred powder.

In a first embodiment, as shown in Fig. 4, each cluster of pre-agglomerated particles is formed by particles of the first type of metal **10** and particles of the second type of metal **11** bonded together by a volatile adhesive **12**. The bond between the two metals is weak enough to be breakable during the press-molding step. This allows the preform to attain a density which both maintains shape under its own weight before the partial sintering step and brings

the particles into close enough proximity to prevent undue flow of melted metal during partial sintering.

As disclosed in Polese et al. U.S. Patent No. 5,413,751, incorporated herein by this reference, the pre-agglomerated clusters may be formed by mixing together separate powders of the different density metals and adding a volatile liquid adhesive to the mixture to form a slurry. The slurry is then atomized into droplets through a process whereby the slurry is subjected to blasts of a gas, typically air, heated to a temperature above the melting point of the volatile liquid adhesive. After drying, the droplets combining all types of particles are continuously collected to form the pre-agglomerated powder.

In another embodiment, as shown in Figure 5, free-flowing powder is made of pre-clustered nodules, where each nodule comprises a grouping of subnodules wherein each subnodule **20** includes a core **21** made of the denser metal surrounded by a blanket of smaller particles **22** of the agglutinating metal.

In another embodiment, referring now to Fig. 6, free-flowing powder is made of pre-clustered nodules, where each nodule **30** comprises a grouping of subnodules **31** wherein each subnodule includes at least one particle **32** of the first type of metal and at least one particle **33** of the second type of metal. The nodules are breakably agglutinated by a binder. Within each subnodule, the particles are paired by surface alloying occurring during the fabrication process.

The desired proportion of the first metal to the second is determined by the relative size or weight of the particles of each subnodule. When this type of powder is compacted into a body, and the body sintered at a temperature slightly above the melting point of the agglutinating metal, the lower melting point agglutinating metal is partially constrained by surrounding particles of non-melted metal, and thereby, prevented from flowing further.

The powder of clustered pre-agglomerated particles shown in Fig. 6 is formed according to a proprietary process developed by OSRAM-SYLVANIA of Towanda, Pennsylvania as disclosed in part in U.S. Patent No. 5,439,638 Houck et al., which is incorporated herein by this reference. The powders of Fig. 5 and 6 are commercially available from that company. More specifically, the powders are respectively designated as Type I and Type III powder electronic grade. The diameters of the nodule range between about 40 and 350 microns. The diameter of the particles range between about 0.5 and 7 microns.

EXAMPLE

A copper and tungsten powder available from Sylvania of Towanda, Pennsylvania sold under the designation TUNGSTAR-Type III was selected that contained approximately 15% copper and 85% tungsten by weight (27.7% and 72.3% per volume). The powder mixture consisted of particles of metal averaging 0.6 to 2.5 microns in diameter.

The powder was then press-molded at room temperature under 2050 atmospheres (30,000 lbs/in^2) into the net shape of the desired liner component. The resulting preform compact was placed in a sintering furnace and subjected to temperatures of approximately 1100°C for about 100 minutes under ambient atmospheric pressure to form a partially sintered body. The body was allowed to cool to a temperature of approximately 300°C whereupon it was placed in a hot stamping press and forged under a pressure of about 3400 atmospheres (50,000 lbs/in^2) to form a forged liner.

After cooling, the liner was then machined to tolerances of about ±0.07 millimeter for the final shaped charge liner.

The final article exhibited a specific gravity of about 96% of theoretical gravity of a perfectly solid composite, and a high homogeneity. No surface bleeding of the copper could be observed on the surface of the liner. The liner exhibited a coefficient of thermal expansion of about 8.0 x 10^{-6}/°C.

Other liners were made with powder having a ratio of copper to tungsten varying between 5 and 30 weight percent copper according to the same process.

While the preferred embodiments of the invention have been described, modifications can be made and other embodiments may be devised without departing from the spirit of the invention and the scope of the appended claims.

WHAT IS CLAIMED IS: